

Effects of ultrasonic vibration on solidification structure and properties of Mg-8Li-3Al alloy

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Received 11 June 2010; accepted 5 January 2011

Abstract: Ultrasonic vibration was introduced into the Mg-8Li-3Al alloy melt during its solidification process. The microstructure, corrosion resistance and mechanical properties of the Mg-8Li-3Al alloy under ultrasonic vibration were investigated. The experiment results show that the morphology of α phase is modified from coarse rosette-like structure to fine globular one with the application of ultrasonic vibration. The fine globular structure is obtained especially when the power is 170 W, and the refining effect also gets better with prolonging the ultrasonic treatment time. The corrosion resistance of the alloy with 170 W of ultrasonic vibration for 90 s is improved apparently compared with the alloy without ultrasonic vibration. The mechanical properties of alloys with ultrasonic vibration are also both improved apparently. The tensile strength and elongation of alloy improve by 9.5% and 45.7%, respectively, with 170 W of ultrasonic treatment for 90 s.

Key words: Mg-8Li-3Al alloy; ultrasonic vibration; corrosion resistance

1 Introduction

Mg-Li series alloys are so called ultra-light magnesium based alloys, and they are the lightest metal structural materials. They have high specific strength and stiffness, good damping capacity, and electromagnetic shielding properties [1–2]. It will reduce the energy consumption if Mg-Li series alloys are successfully widespread applied. But the strength of Mg-Li alloys at room temperature especially at high temperature is low [3]. Additionally, the alloys have poor corrosion resistance, which limits their applications [4–6].

Several previous investigations proposed that high intensity ultrasonic treatment was one of the effective ways to improve the solidification structure of metals [7–9]. Ultrasonic vibration of aluminum alloys had been studied extensively, and it can effectively refine the grain size. But few researches on magnesium-lithium base alloys with ultrasonic in solidification process were done before. In the present work, ultrasonic vibration was applied during the solidification process of the Mg-8Li-3Al alloy. The effects of ultrasonic vibration on

microstructure, corrosion resistance and mechanical properties of the super light magnesium alloys were studied. The refinement mechanism of ultrasonic vibration was discussed.

2 Experimental

The Mg-8Li-3Al alloy was treated by a commercial high intensity ultrasonic equipment. The ultrasonic equipment is comprised of a 20 kHz ultrasonic power, an ultrasonic transducer made of piezoelectric ceramics, an ultrasonic amplitude transformer and an ultrasonic probe. The ultrasonic amplitude transformer and probe are made of stainless steel.

The Mg-8Li-3Al alloy was prepared by using ingots of pure magnesium (99.9%), pure lithium (99.9%), and pure aluminum (99.9%). The experimental alloy was molten in a steel crucible (the ratio of height to diameter is 3:1) set in an electric resistance furnace under an argon atmosphere. The melt was covered with a molten flux of 75% LiCl+25% LiF [10–11]. The schematic diagram of the experiment apparatus is shown in Fig. 1. The stainless steel mould (diameter: 60 mm, height: 160 mm) with the

Foundation item: Project (2009AA03Z525) supported by the High-tech Research and Development Program of China; Project (NCET-08-0080) supported by the Program of New Century Excellent Talents of the Ministry of Education of China; Project (20082172) supported by the Natural Science Fund of Liaoning Province, China; Project (2009J21DW003) supported by the Science and Technology Fund of Dalian City, China

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DOI: 10.1016/S1003-6326(11)60848-0

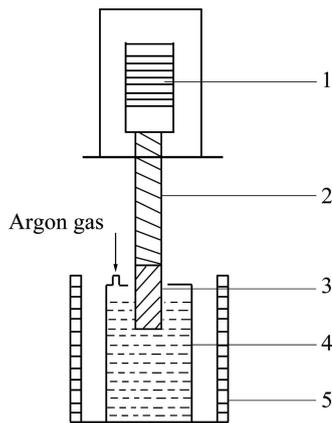


Fig. 1 Schematic diagram of experiment apparatus: 1—Ultrasonic transducer; 2—Amplitude transformer; 3—Ultrasonic probe; 4—Stainless steel mould; 5—Heat preserving furnace

preheated temperature of 600 °C was transferred to the heat preserving furnace, and then the melt was poured into stainless steel mould for ultrasonic treatment. The insertion depth of ultrasonic probe was 20 mm from the top of the liquid metal. The ultrasonic probe was withdrawn from the melt after the melt was treated for certain seconds, and immediately the mould was removed from the heat preserving furnace to the air. For comparison, samples without ultrasonic vibration were also made.

Microstructure characterization was examined using optical microscopy. Particle size D_i of α phase can be defined as

$$D_i = 2(A_i/\pi)^{1/2} \quad (1)$$

and particle roundness of α phase is

$$f_i = P_i^2 / (4\pi A_i) \quad (2)$$

where A_i is the cross-sectional area of α phase and P_i is the perimeter of α phase.

3 Results and discussion

3.1 Microstructure

The optical micrographs of the specimens obtained without and with ultrasonic vibration at different powers are shown in Fig. 2. Ultrasonic vibration of 20 kHz with 0, 50, 110, 170, 210, 260 W were employed for 90 s. Microstructures of Mg-8Li-3Al alloy are changed respectively according to the ultrasonic powers. BCC structured β phase of Li solid solution coexists with the HCP structured α phase of Mg solid solution (Fig. 2). Without ultrasonic vibration treatment, α phase looks like a coarse rosette structure surrounded by β phase, as shown in Fig. 2(a). In contrast, with the application of ultrasonic vibration, the morphology of α phase is

modified from coarse rosette-like structure to finely somewhat globular one, and as the ultrasonic power increases, the refining effect of α phase increases visibly until the power is 170 W. But the morphology of α phase becomes somewhat coarse at 260 W of ultrasonic power compared with 170 W of ultrasonic power. Figure 3 shows that the particle size and roundness of α phase begin to decrease and then increase while the power increases, the particle size is the smallest and the roundness is around 2 (1 means perfect roundness) when the power is 170 W.

The particle size and roundness of α phase decrease, as shown in Fig. 4. It demonstrates that α phase is finer and rounder with increasing ultrasonic vibration time with 170 W of ultrasonic power. Figure 5 shows the microstructures of specimens obtained by ultrasonic vibration treatment of 170 W for different time.

It is clear that ultrasonic vibration has a significant effect on grain refining. Mechanism for grain refinement under ultrasonic vibration has been proposed based on cavitation effect and acoustic steaming [12–13]. Ultrasonic vibration induces cavitation bubbles, which will collapse at a very high speed, and generate high instantaneous temperature and pressure. As for the Mg-8Li-3Al alloy, its volume decreases when it transforms from liquid to solid. The high instantaneous pressure raises the freezing point of Mg-8Li-3Al alloy, corresponding increases the undercooling of the melt, and promotes the nucleation in the melt. A large number of nuclei can be produced, and be distributed in other parts of the melt by the acoustic streaming. Acoustic streaming promotes the heat transfer and element diffusion, thus accelerates the remelting of dendrites at their roots during the growth of the newly formed nuclei. As shown in Fig. 2, microstructures with ultrasonic vibration become more globular and finer. Ultrasonic vibration will generate heat when the ultrasonic power increases [14]. When ultrasonic power is 260 W, it generates more heat, which decreases the cooling rate. This may be the reason why the morphology of α phase is somewhat coarse at 260 W of ultrasonic power compared with 170 W of ultrasonic power. Cavitation effect and acoustic steaming have become noticeably stronger with prolonging the ultrasonic treatment time when the ultrasonic power is 170 W. The refining effect is also getting better, as shown in Fig. 5.

3.2 Corrosion resistance

Figure 6 shows the polarization curves of the Mg-8Li-3Al alloy without and with 170 W of ultrasonic vibration power in 3.5% NaCl solution. Without ultrasonic vibration, the corrosion potential is -1.36 V, and the corrosion current density is 1.65×10^{-3} A/cm². After ultrasonic vibration treatment, the corrosion

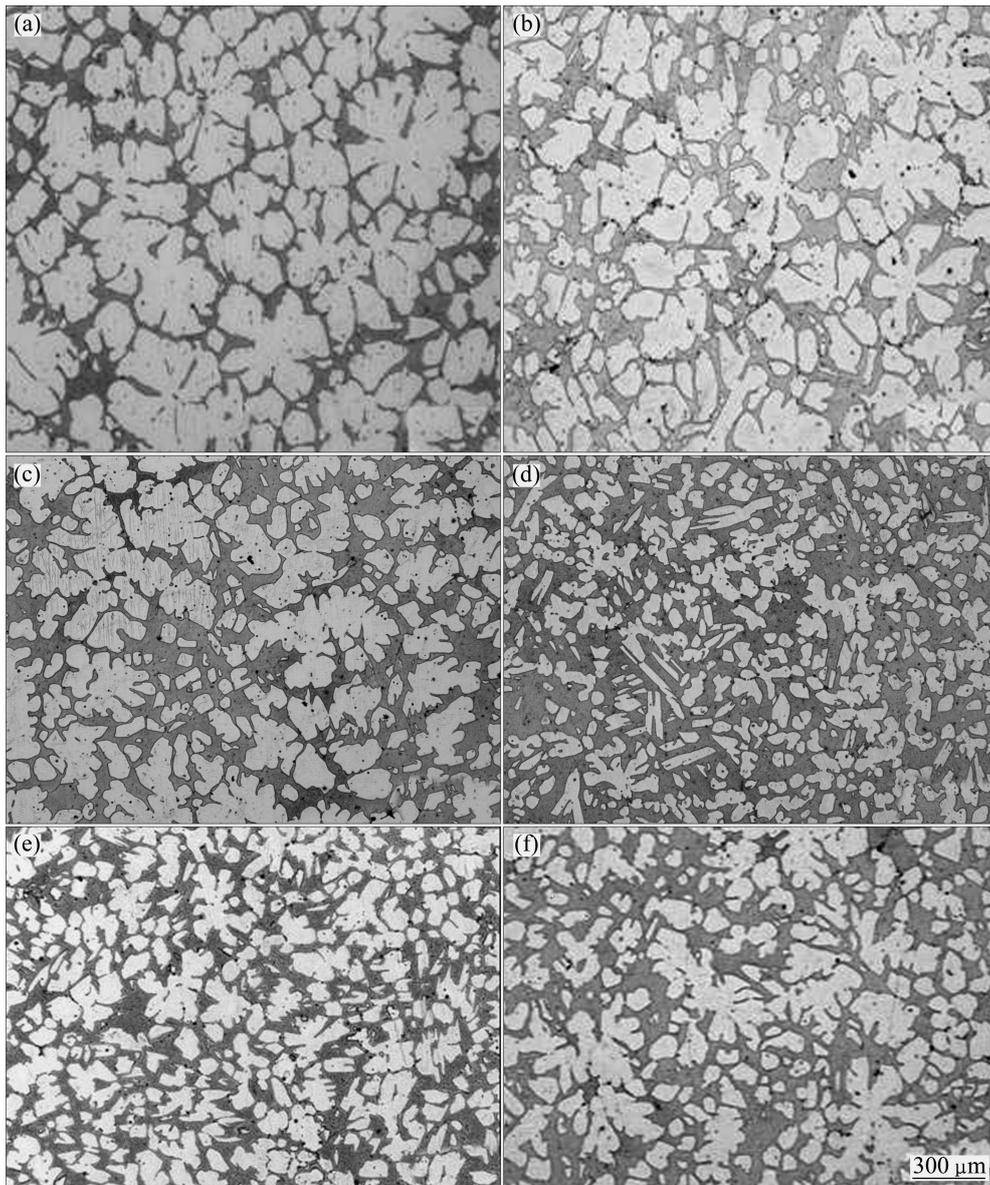


Fig. 2 Microstructures of specimens obtained with different ultrasonic vibration powers: (a) 0 W; (b) 50 W; (c) 110 W; (d) 170 W; (e) 210 W; (f) 260 W

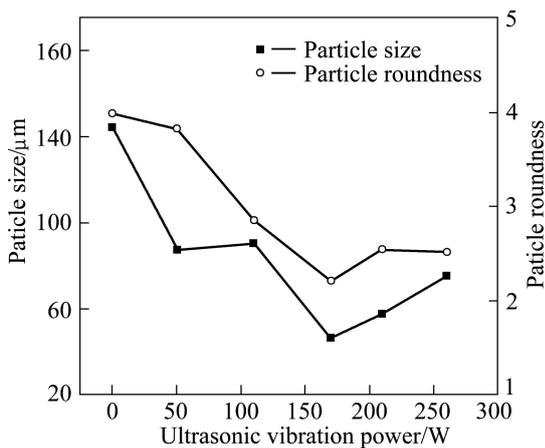


Fig. 3 Effects of ultrasonic vibration power on particle size and roundness of α phase

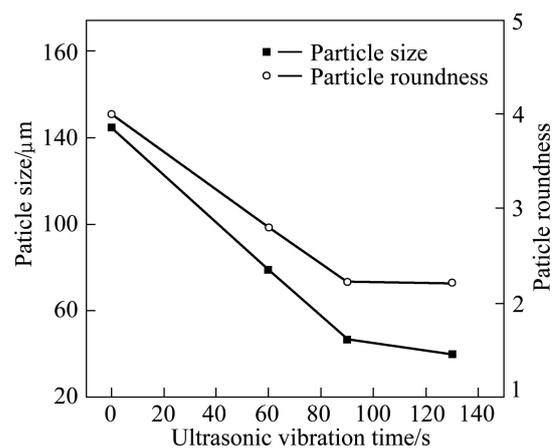


Fig. 4 Effects of ultrasonic vibration time with 170 W on particle size and roundness of α phase

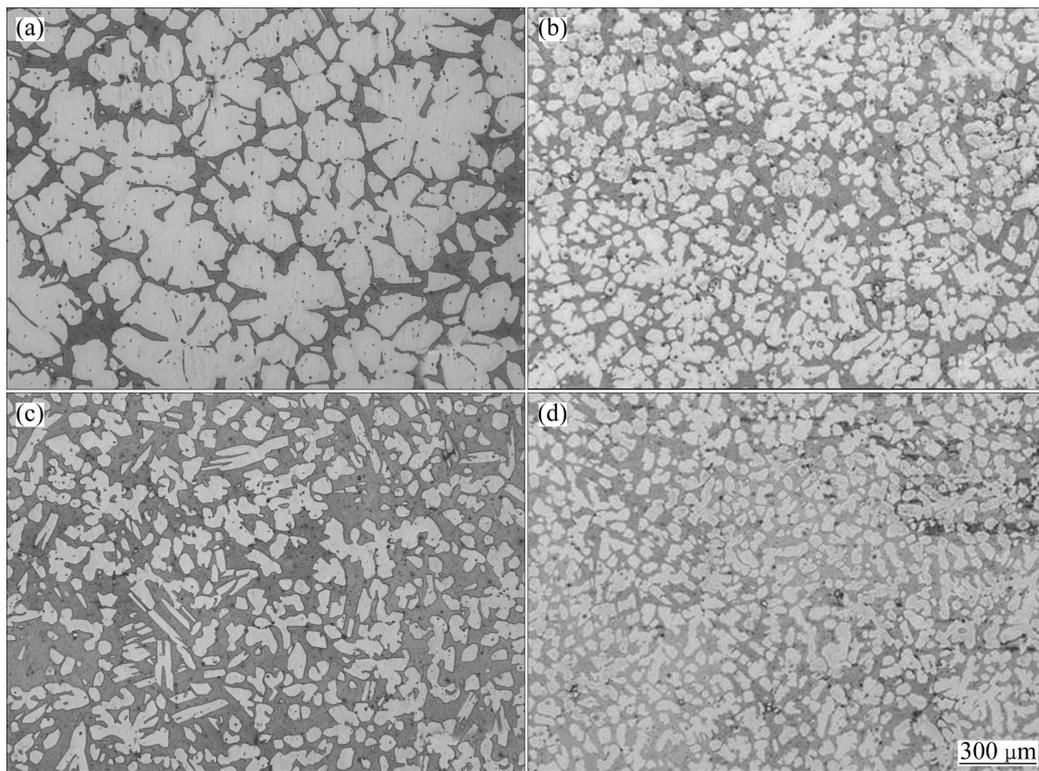


Fig. 5 Microstructures of specimens obtained with 170 W for different time: (a) 0 s; (b) 60 s; (c) 90 s; (d) 130 s

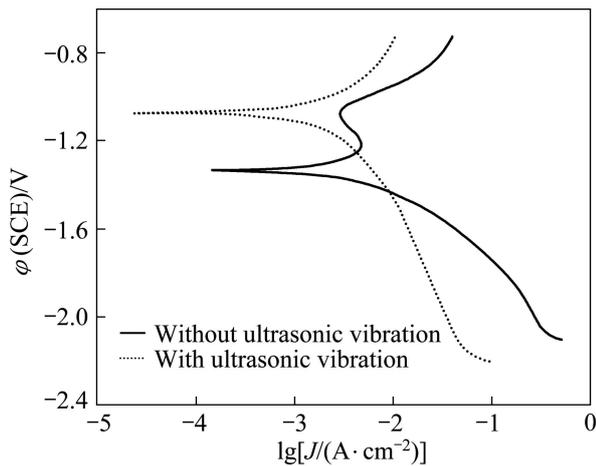


Fig. 6 Polarization curves of Mg-8Li-3Al alloy with 170 W without and with ultrasonic vibration

potential is -1.07 V, and the corrosion current density is 5.96×10^{-4} A/cm². The results reveal that the Mg-8Li-3Al alloy has negative corrosion potential, which accordingly has high activity. Compared with the alloy without ultrasonic vibration, the corrosion potential of the one with ultrasonic vibration is greater, and the corrosion current density is smaller. This indicates that the corrosion resistance of the Mg-8Li-3Al alloy with ultrasonic vibration is better than the one without vibration.

Figure 7 shows the corrosion morphologies of the

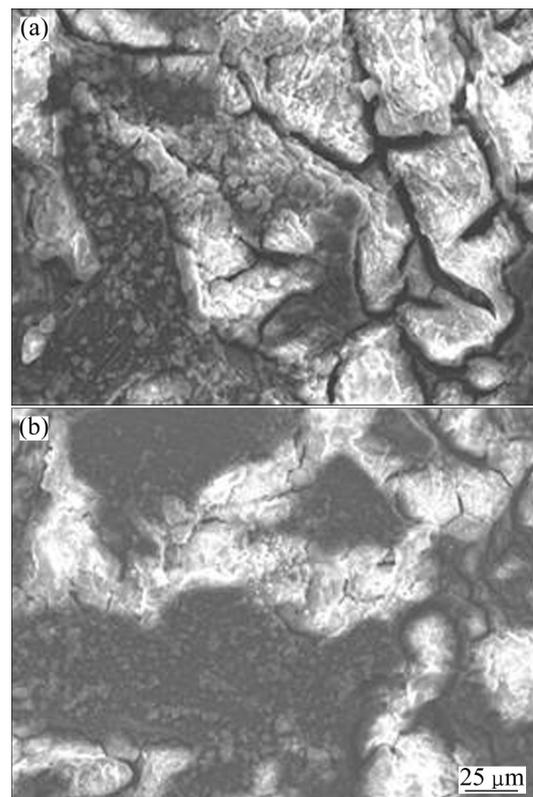


Fig. 7 SEM images of Mg-8Li-3Al alloy after being immersed in 3.5% NaCl solution for 16 h: (a) Without ultrasonic vibration; (b) With ultrasonic vibration

Mg-8Li-3Al alloy without and with 170 W of ultrasonic vibration power after being immersed in 3.5% NaCl solution for 16 h. Some cracks are visible on the white α phase, and there are more and bigger cracks in Fig. 7(a). Some white spotted corrosion products are visible on the β phase, and many more spotted corrosion products on the β phase are shown in Fig. 7(a) than Fig. 7(b). This indicates that the corrosion resistance of the Mg-8Li-3Al alloy with ultrasonic vibration is better than the one without vibration. The result is consistent with the previously polarization curves test.

3.3 Mechanical properties

The mechanical properties of the Mg-8Li-3Al alloys by ultrasonic vibration treatment with different powers for 90 s are shown in Fig. 8. It can be seen that the tensile strength and elongation are increased markedly with ultrasonic vibration treatment. When the power is less than 110 W, they are changed little because the power is not large enough. The tensile strength and elongation are 184 MPa and 18.5%, respectively, with 170 W of ultrasonic vibration power treatment for 90 s. Compared with the Mg-8Li-3Al alloy without ultrasonic vibration, the tensile strength of the one with 170 W of ultrasonic vibration increases by 9.5%, and the elongation improves by 45.7%. But both the tensile and elongation decrease when power is more than 170 W.

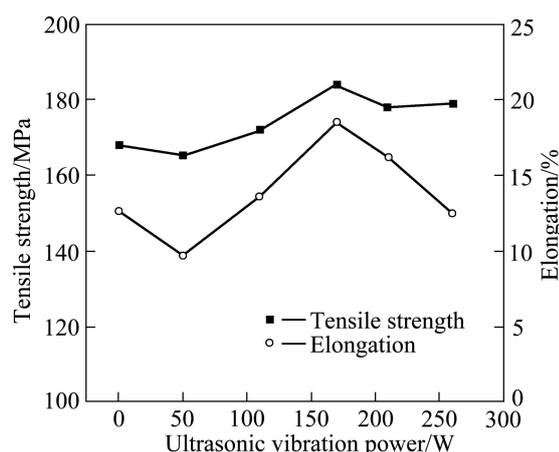


Fig. 8 Mechanical properties of Mg-8Li-3Al alloys by ultrasonic vibration treatment with different powers for 90 s

There is a close relationship between the mechanical properties and microstructures[15]. The results exhibit that the mechanical properties match the Hall-Petch relationship. Microstructures affect the mechanical properties. When the power is less than 110 W, rosette-like microstructures are changed little, and the mechanical properties have a little change. When α phase of the alloy with 170 W of ultrasonic vibration power treatment is obviously refined, the mechanical properties are increased significantly. When power increases, the

morphology of microstructure becomes somewhat coarse, as well as the mechanical properties decrease.

4 Conclusions

1) Mg-8Li-3Al alloy consists of a dual phase structure of α and β phases, the morphology of α phase is modified from coarse rosette-like structure to finely globular one with the application of ultrasonic vibration. The finely globular structure is obtained especially when the power is 170 W, and the refining effect is also getting better with prolonging the ultrasonic treatment time.

2) Mg-8Li-3Al alloy is easy to be corroded, but the corrosion resistance of the alloy is improved apparently with the application of ultrasonic vibration. Compared with the alloy without ultrasonic vibration, the corrosion potential of the alloy with ultrasonic vibration is greater, and the corrosion current density is smaller. The Mg-8Li-3Al alloy with ultrasonic vibration was also corroded after being immersed in 3.5% NaCl solution for 16 h, but to a less degree compared with the alloy without ultrasonic vibration.

3) The mechanical properties of the alloy with ultrasonic vibration increase significantly. Compared with the alloy without ultrasonic vibration, the tensile strength of the one with 170 W of ultrasonic vibration for 90 s increases by 9.5%, and the elongation improves by 45.7%.

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超声振动对 Mg-8Li-3Al 合金凝固组织及性能的影响

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摘要: 在 Mg-8Li-3Al 合金的凝固过程中, 不同功率的超声波被引入到合金熔体中。在超声作用下研究 Mg-8Li-3Al 合金的微观结构、耐腐蚀性能和力学性能。基于超声空化作用及声流作用, 对超声细化机制进行分析。结果表明: 在施加超声波后, 合金的 α 相形貌从粗大的蔷薇状结构变为细小的近球状结构。当超声波功率为 170 W 时, 能够获得细小的球状结构。与没有施加超声场的合金相比, 施加超声场(功率 170 W, 作用时间 90 s)后的合金耐腐蚀性明显提高, 力学性能也有很大改善, 抗拉强度和伸长率分别提高了 9.5% 和 45.7%。

关键词: Mg-8Li-3Al 合金; 超声振动; 耐腐蚀性

(Edited by LI Xiang-qun)